Regional Haze Visibility Basics

Montana BART stakeholder's

Meeting

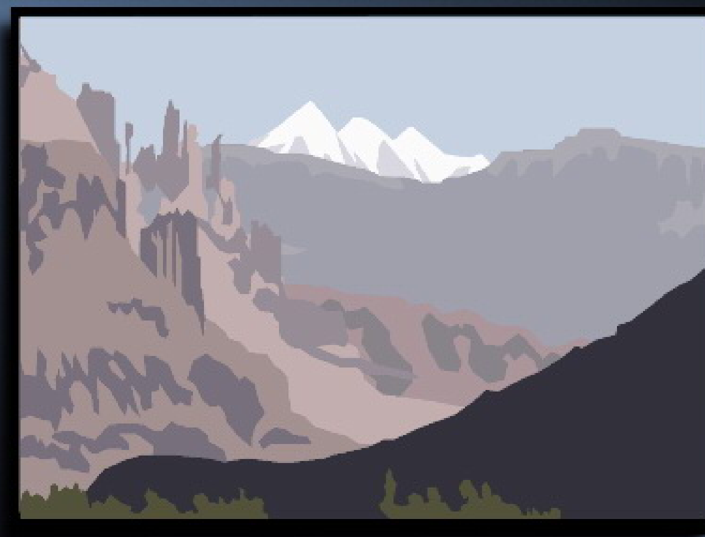
January 17, 2008

How far can you see?

Types of Visibility Impairment

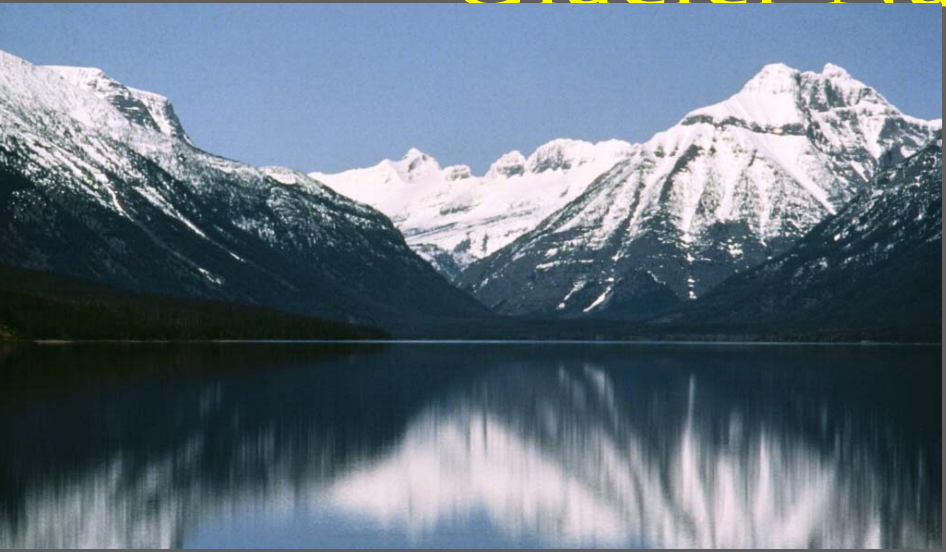
Layered Haze

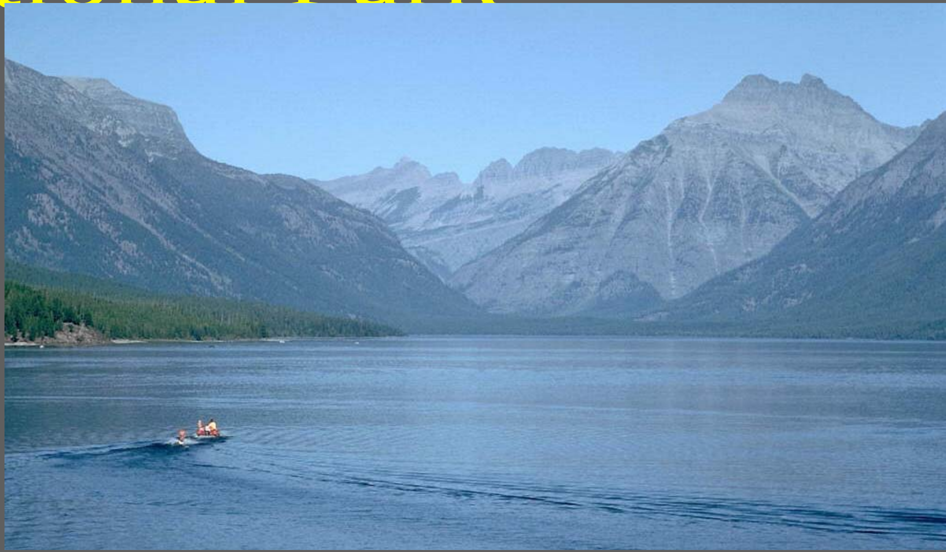
Plume



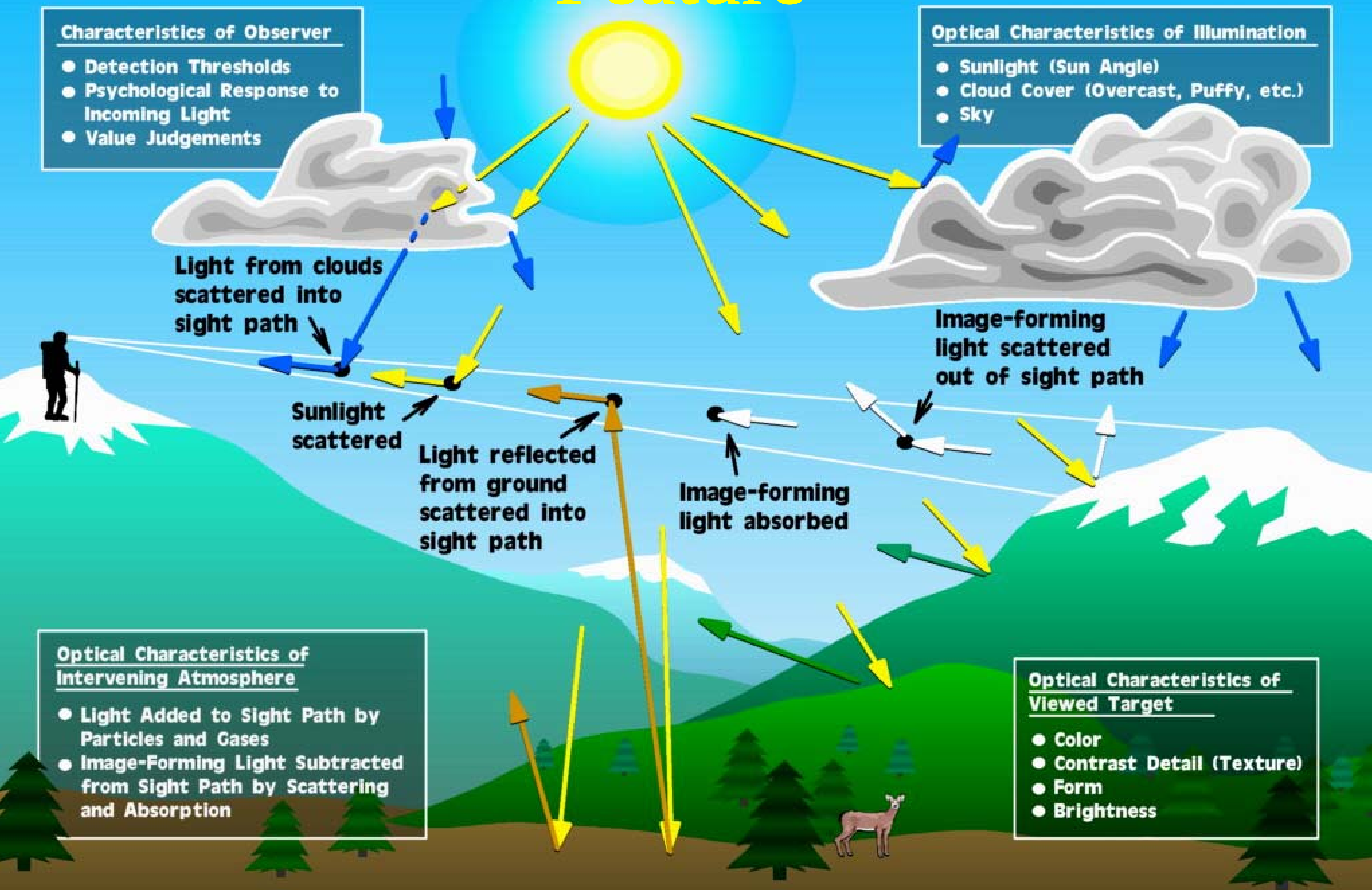
Uniform Haze

Glacier National Park

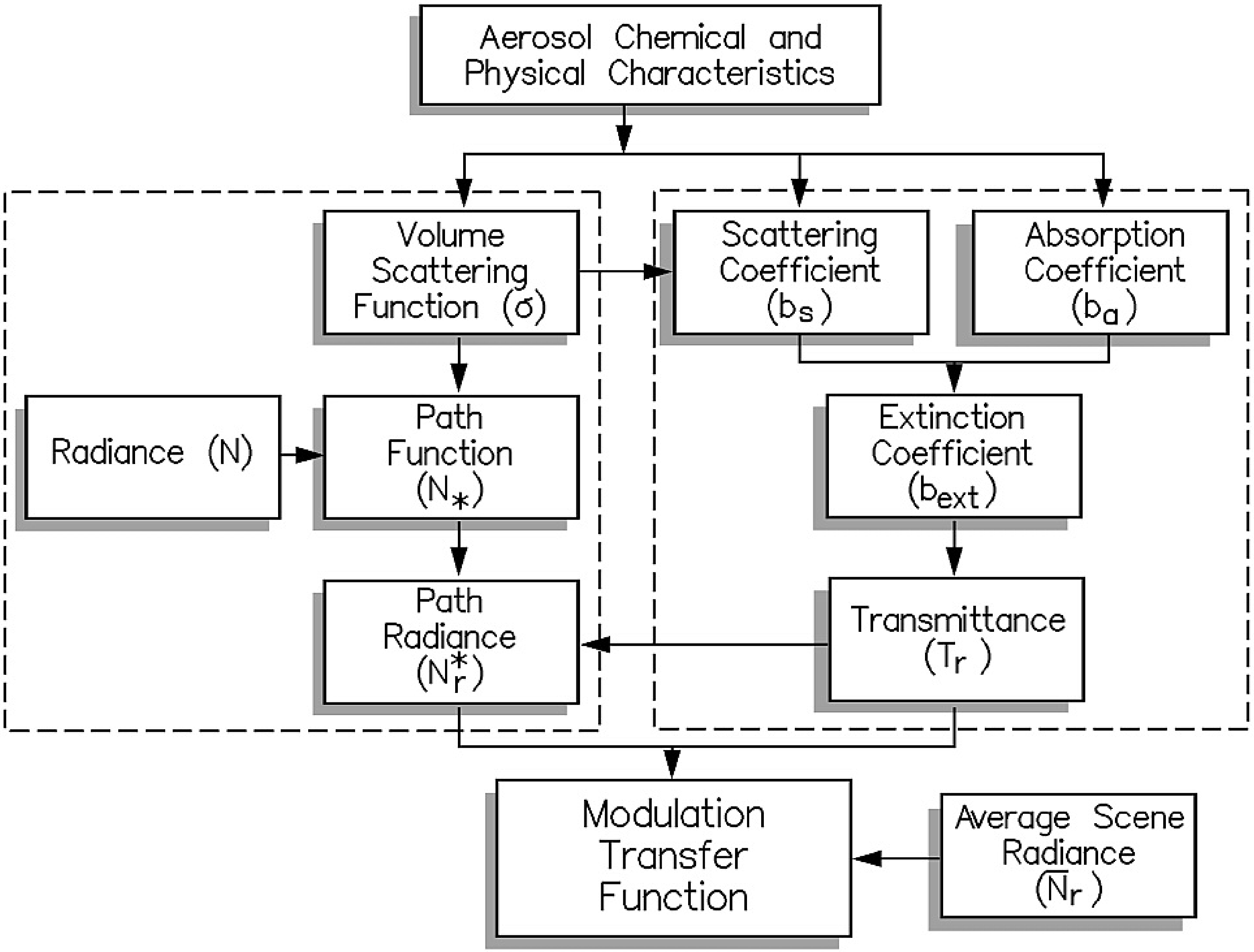




The Seeing of a Landscape Feature



Relationship Between Aerosols



Visual Range (V.R.):

- The greatest distance at which an observer can just see a black object viewed against the horizon sky.
- **Units**: Distance, e.g. kilometers (km)
- **Relationships**:

- $V.R. = K/b_{ext}$

- Where K is the Koschmieder Coefficient – the log of the contrast threshold of the human eye, K = 3 – 3.9
- For Regional Haze Rule K is 3.912

Light Extinction (b_{ext}):

- The attenuation of light due to scattering and absorption as it passes through a medium.
- **Units**: inverse distance, e.g. inverse mega meters (Mm^{-1})
- **Relationships**:
- b_{ext} = K/V.R.
  b_{ext} = 10*exp(DV/10)

Deciview (DV):

- A metric of haze proportional to the logarithm of the atmospheric extinction (b_{ext}).
- **Units**: Unitless
- **Relationships**:

- $DV = 10*\ln(b_{ext}/10)$

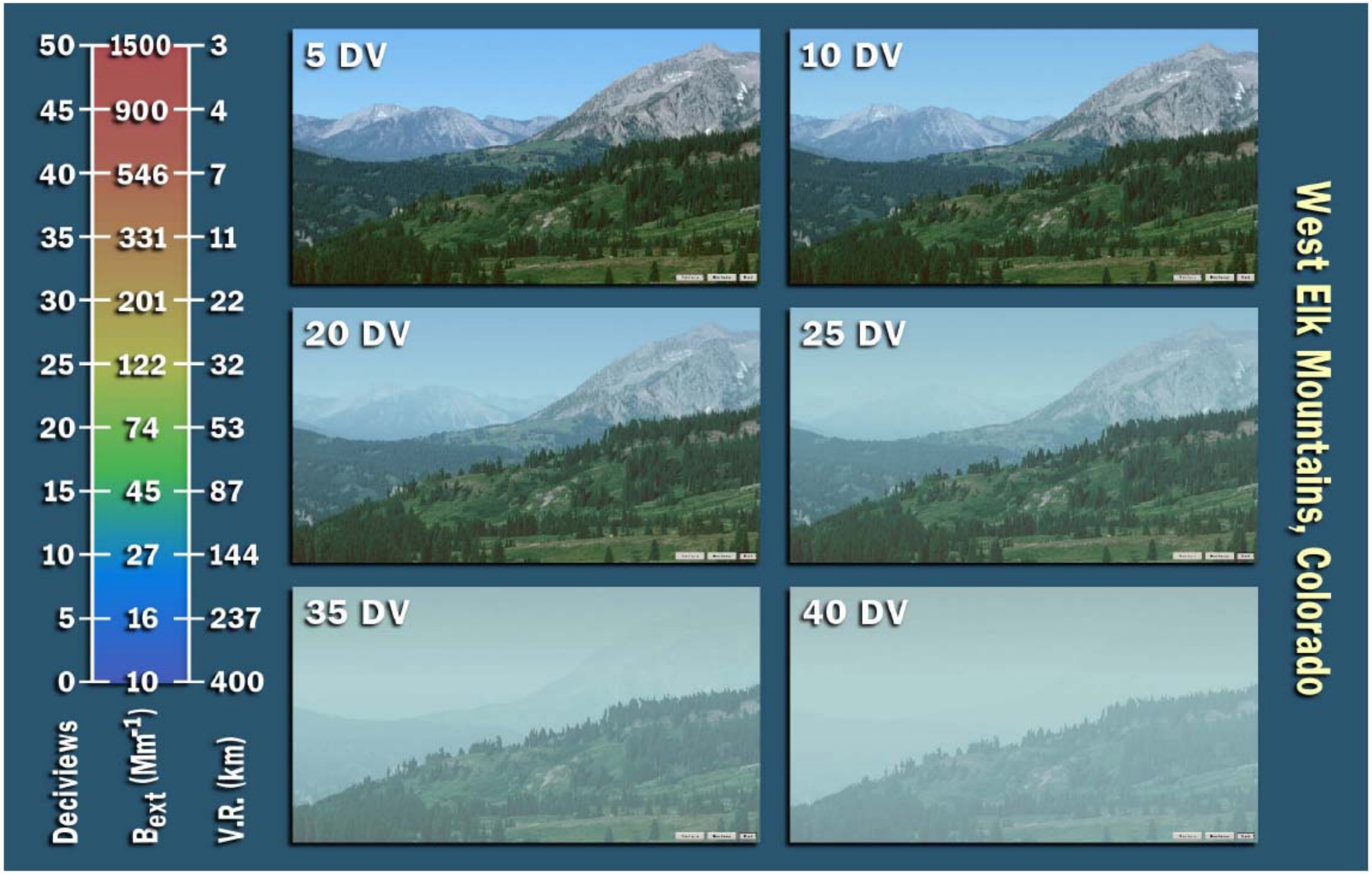
EXACT

$$VR\ (\mathrm{km}) * b_{ext}\ (\mathrm{Mm}^{-1}) = 3912$$

GOOD ENOUGH

$$VR\ (\mathrm{km}) * b_{ext}\ (\mathrm{Mm}^{-1}) = 4000$$

Demonstration of DV and Other Visibility Scales



Extinction =

The extinction coefficient is made up of particle and gas scattering and absorption:

$$b_{ext} = b_{sg} + b_{ag} + b_{sp} + b_{ap}$$

where s, a, g, and p refer to scattering, absorption, gases, and particles, respectively.

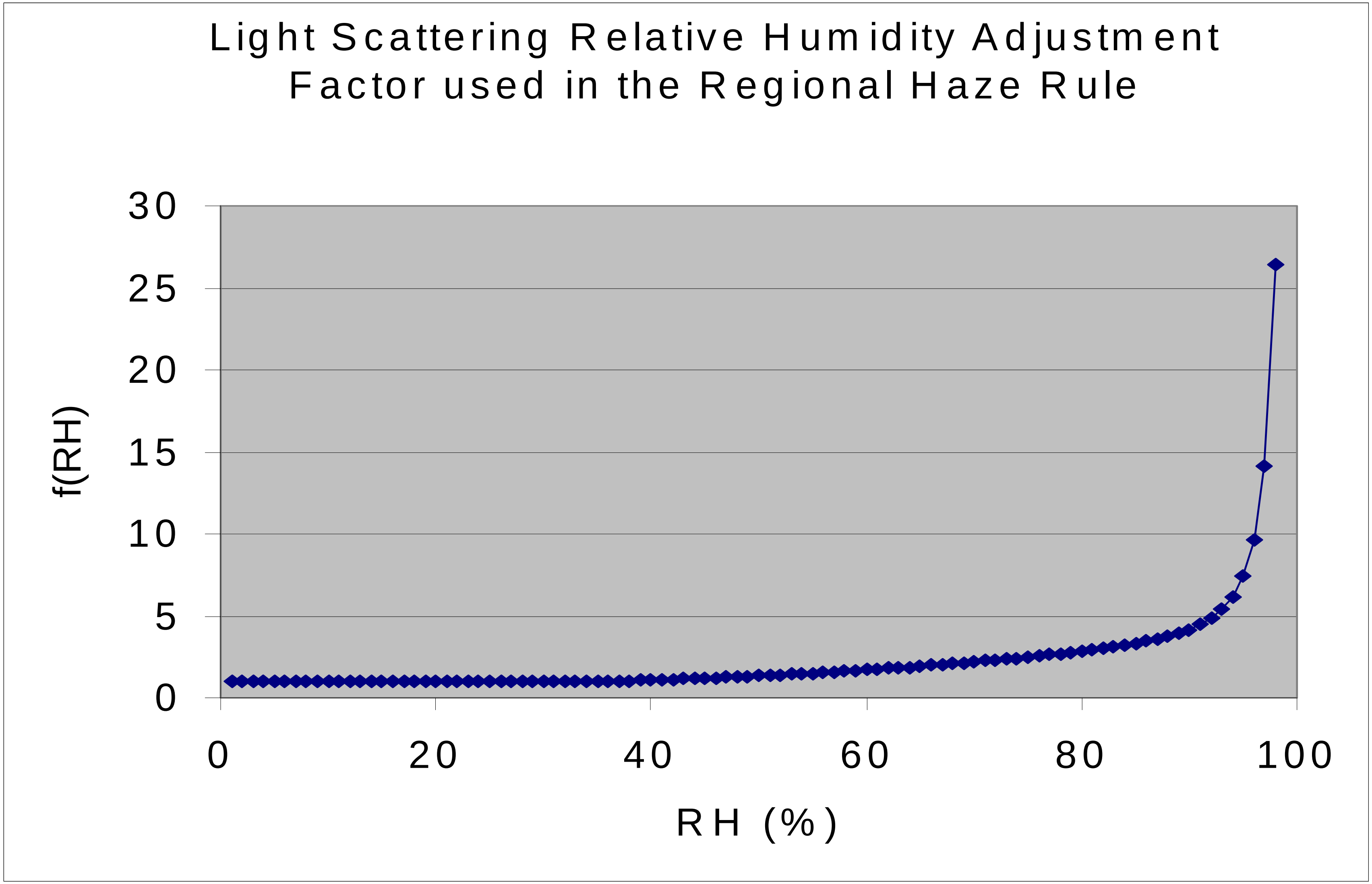
Haze Metric

- Estimate light extinction from IMPROVE particle data

$$
\begin{aligned}
b_{ext} \approx\; & 3 \times f(RH) \times [Sulfate] \\
& + 3 \times f(RH) \times [Nitrate] \\
& + 4 \times [Organic\ \ Carbon] \\
& + 10 \times [Elemental\ \ Carbon] \\
& + 1 \times [Fine\ \ Soil] \\
& + 0.6 \times [Coarse\ \ Mass] \\
& + 10
\end{aligned}
$$

- Calculate best and worst haze conditions
  - Each year identify and average the 20% of days with the largest (worst) and the 20% smallest (best) light extinction
  - Calculate mean of the best and worst for 5-year periods *[**baseline:** 2000 to 2004, first trend point: 2005 to 2009, etc.]*
  - Daily, best & worst values are available for each site from the IMPROVE and VIEWS web sites

F (RH) ??



Light Scattering Relative Humidity Adjustment Factor used in the Regional Haze Rule
f(RH)
30
25
20
15
10
5
0
0
20
40
60
80
100
RH (%)

Annual Mean Natural Background Aerosol Estimates[1]

Particle Component	East (µg/m³)	West (µg/m³)	Error Factor
$PM_{2.5}$			
Sulfate (NH_4HSO_4)	0.2	0.1	2
Organics	1.5	0.5	2
Elemental Carbon	0.02	0.02	2 – 3
Ammonium Nitrate	0.1	0.1	2
Soil Dust	0.5	0.5	1.5 – 2
Water	1.0	0.25	2
PM_{10}	3.0	3.0	1.5 - 2

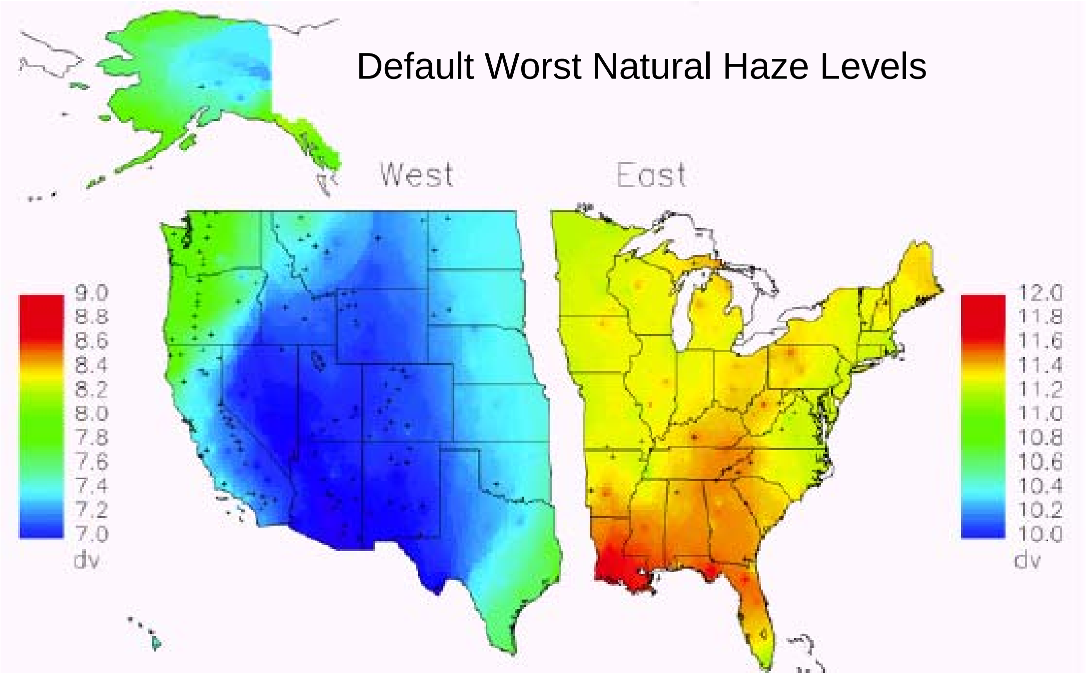
1. From John Trijonis, NAPAP State of Science #24, Appendix A, 1991

Default Natural Levels

- Estimates of natural species concentrations for West & East based on work by John Trijonis for NAPAP in the late 1980s

Component	Average Concentration E/W (μg/m³)	Trijonis' Error Factor	Dry Extinct. Efficiency (m²/g)	Dry PM Extinction (Mm⁻¹)
Ammonium sulfate	0.23/0.12	2	3	0.69/0.36
Ammonium nitrate	0.1	2	3	0.3
Organics (POM)	1.4/0.47	2	4	5.6/1.88
Elemental carbon	0.02	2 - 3	10	0.2
Fine soil	0.5	1.5 - 2	1	0.5
Coarse matter	3.0	1.5 - 2	0.6	1.8
Sum	**Fine 2.25/1.21** **Coarse 3.0**			**9.09/5.04**

- East – West dichotomy due principally to Organic Carbon and Ammonium Sulfate
- Variations within East & West are due to geographic variations in relative humidity



Haze Algorithm Complications

- In response to criticisms IMPROVE has adopted a new algorithm to estimate haze, that includes
  - sea salt term based on chloride data,
  - site-specific Rayleigh based on elevation & T,
  - larger ratio of organic mass to organic carbon (1.8 instead of 1.4)
  - split terms for sulfate, nitrate, & organic into two size distribution each with new f(RH)

New IMPROVE Haze Algorithm

$$
\begin{aligned}
b_{ext} \approx\ & 2.2 \times f_S(RH) \times [\text{Small Sulfate}] + 4.8 \times f_L(RH) \times [\text{Large Sulfate}] \\
& + 2.4 \times f_S(RH) \times [\text{Small Nitrate}] + 5.1 \times f_L(RH) \times [\text{Large Nitrate}] \\
& + 2.8 \times [\text{Small Organic Carbon}] + 6.1 \times [\text{Large Organic Carbon}] \\
& + 10 \times [\textit{Elemental Carbon}] \\
& + 1 \times [\textit{Fine Soil}] \\
& + 1.7 \times f_{SS}(RH) \times [\text{Sea Salt}] \\
& + 0.6 \times [\textit{Coarse Mass}] \\
& + \text{Rayleigh Scattering (Site Specific)} \\
& + 0.33 \times [NO_2(\text{ppb})]
\end{aligned}
$$

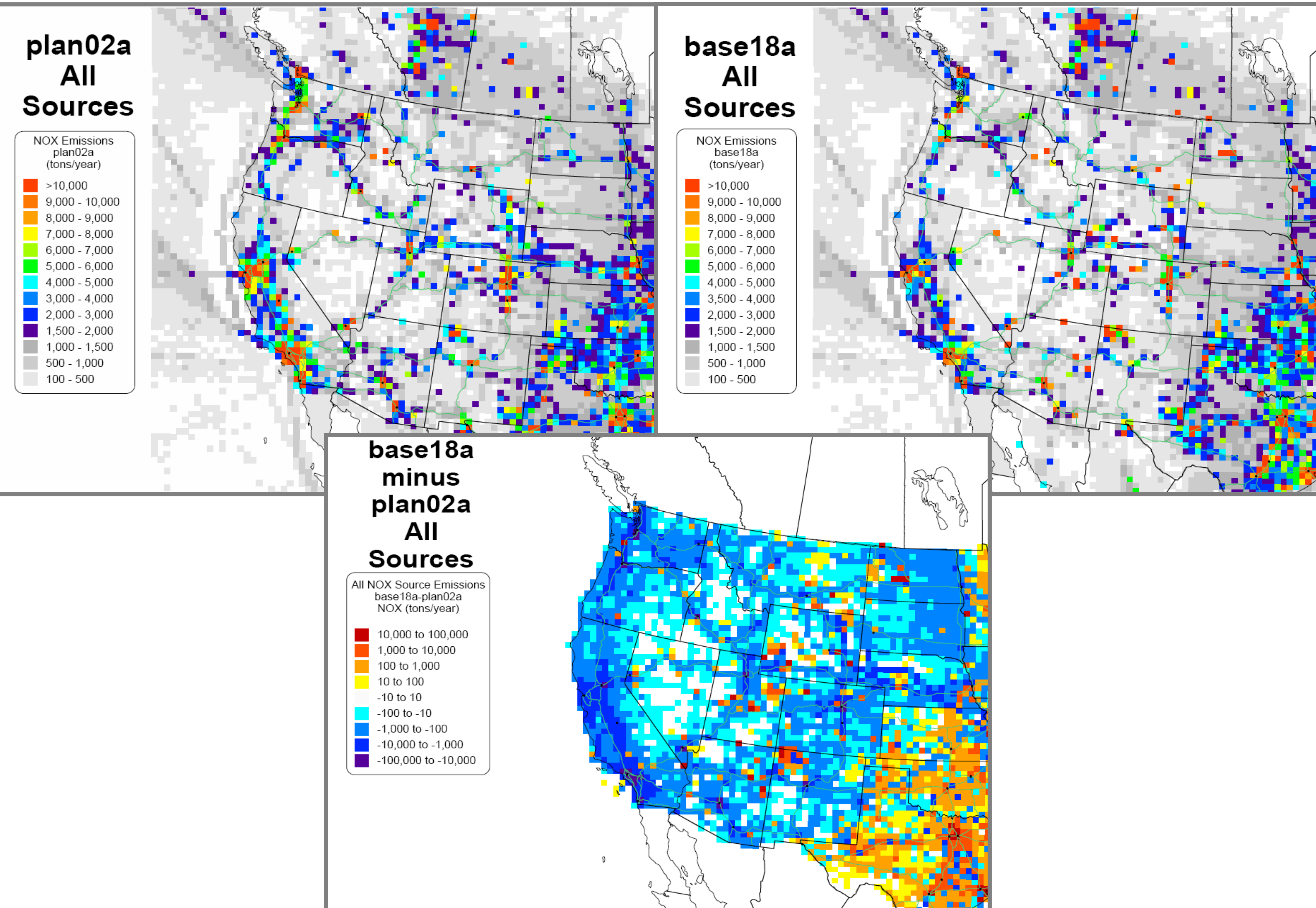
where $[Large\ Sulfate] = \frac{[Total\ Sulfate]}{20} \times [Total\ Sulfate],\ for\ [Total\ Sulfate] < 20$

$$[Large\ Sultate] = [Total\ Sulfate],\ for\ [Total\ Sulfate] \geq 20$$

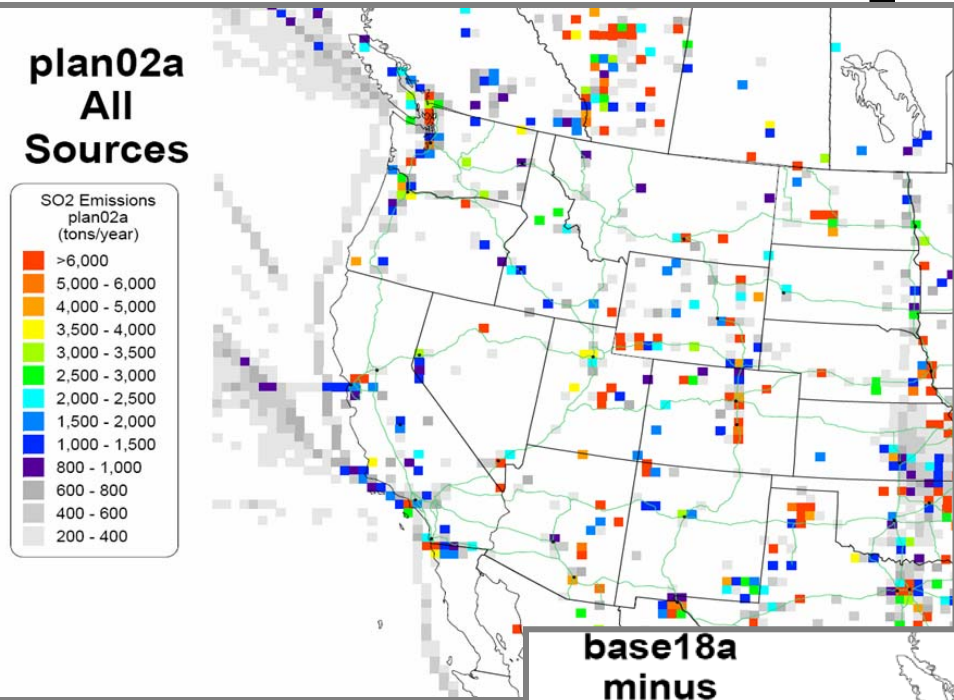
$$[Small\ Sulfate] = [Total\ Sulfate] - [Large\ Sulfate]$$

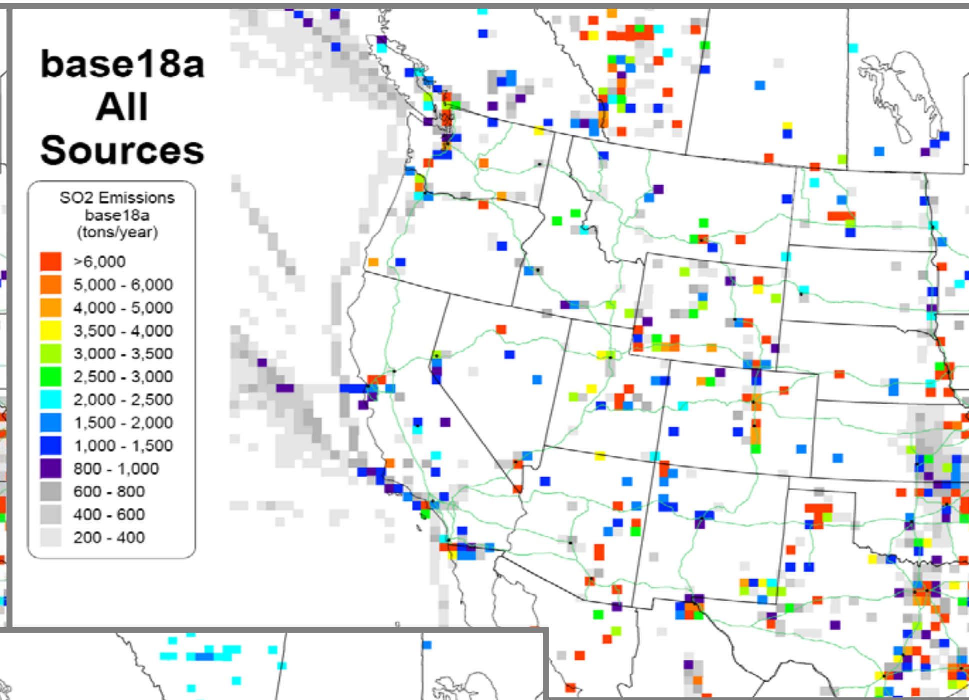
and nitrate and organic are split using the same process

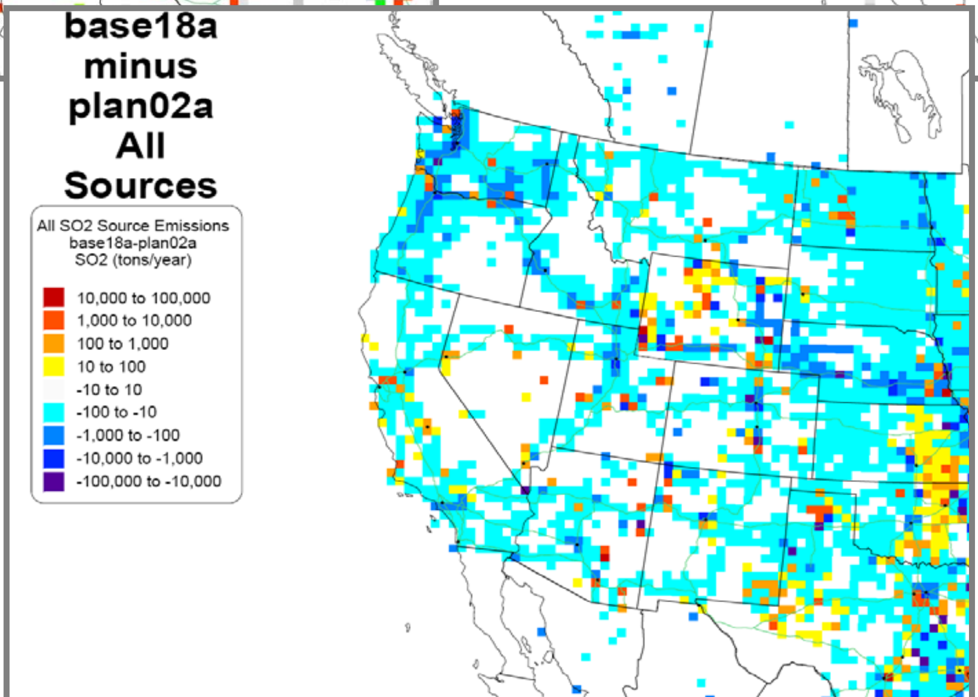
All NOx Emissions



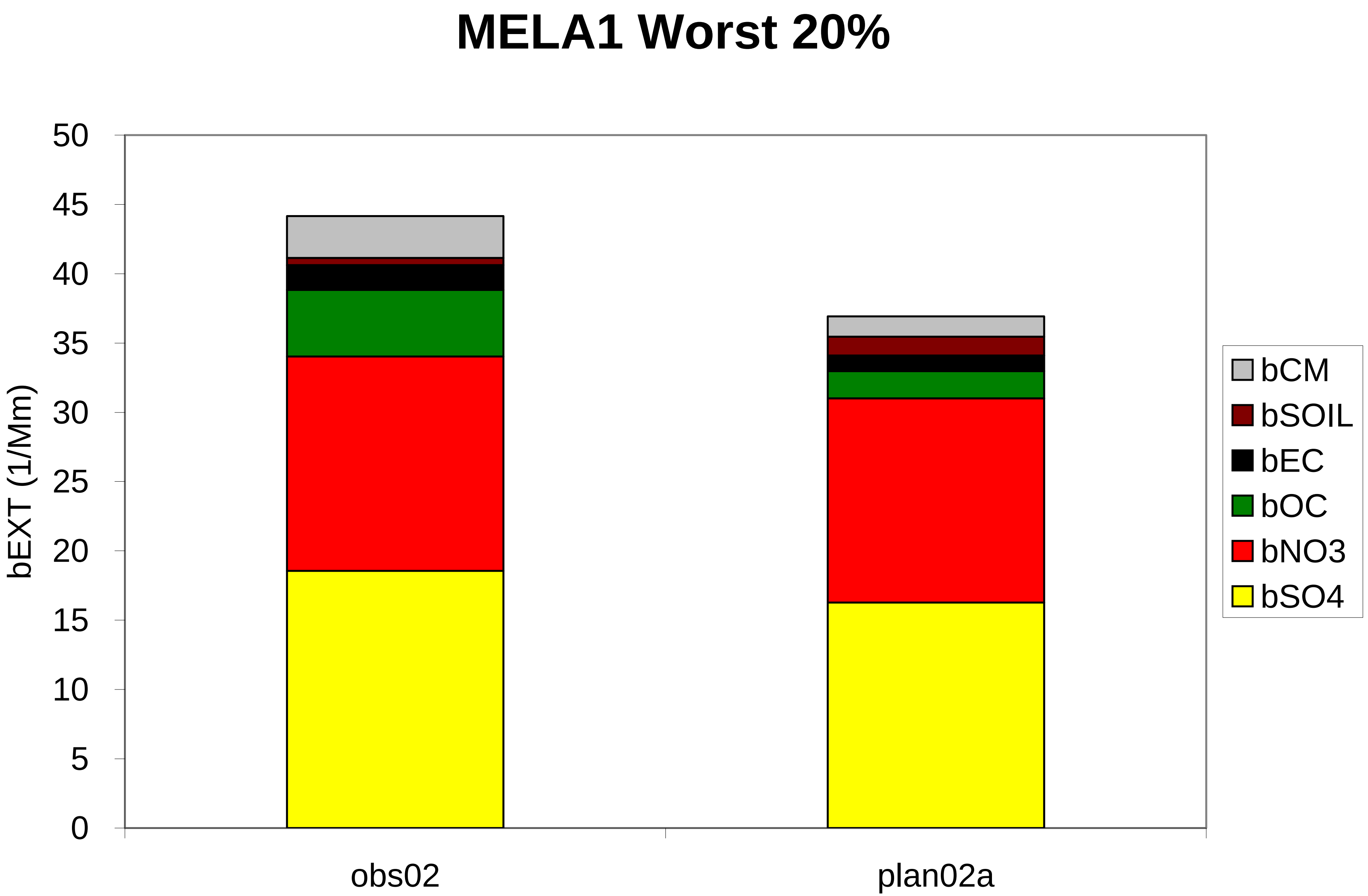
All SO_2 Emissions

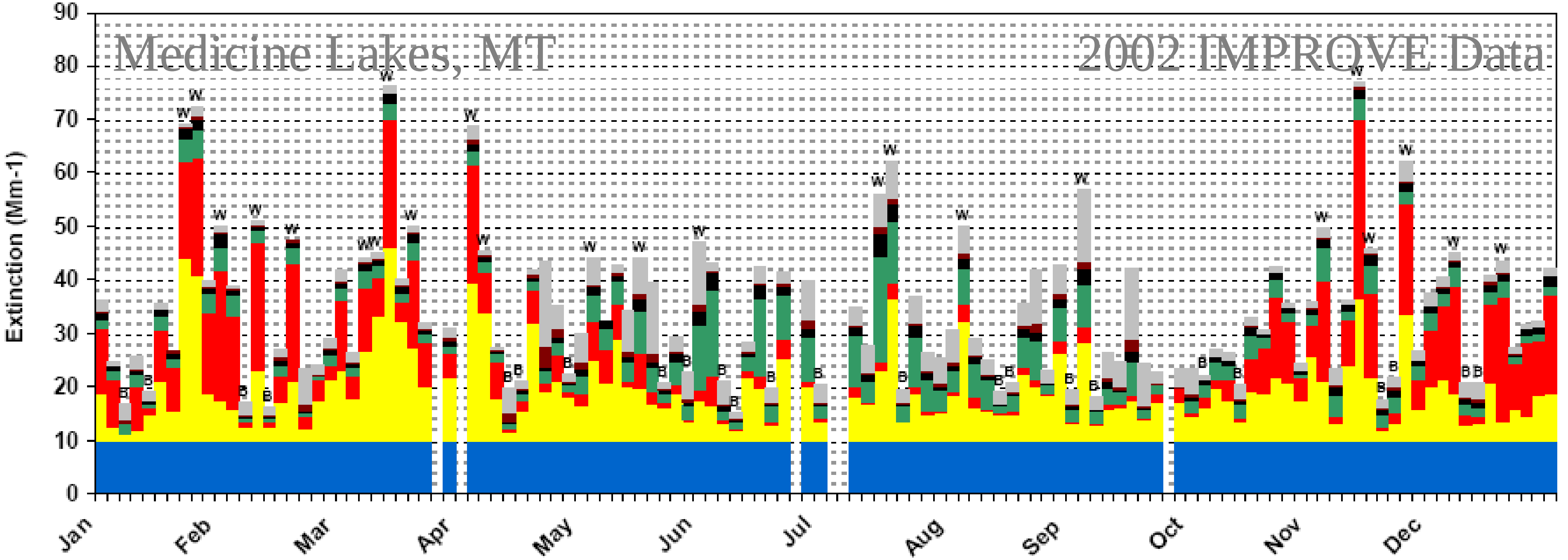




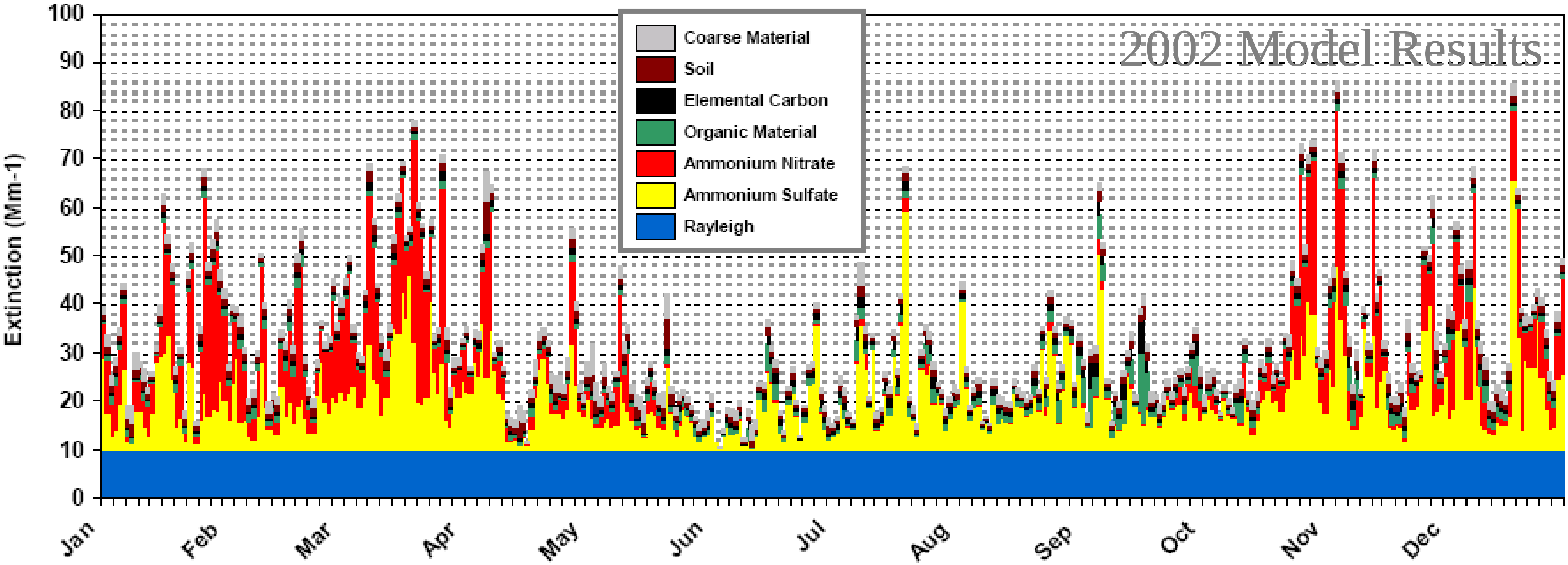


Model Comparison: Medicine Lakes, MT



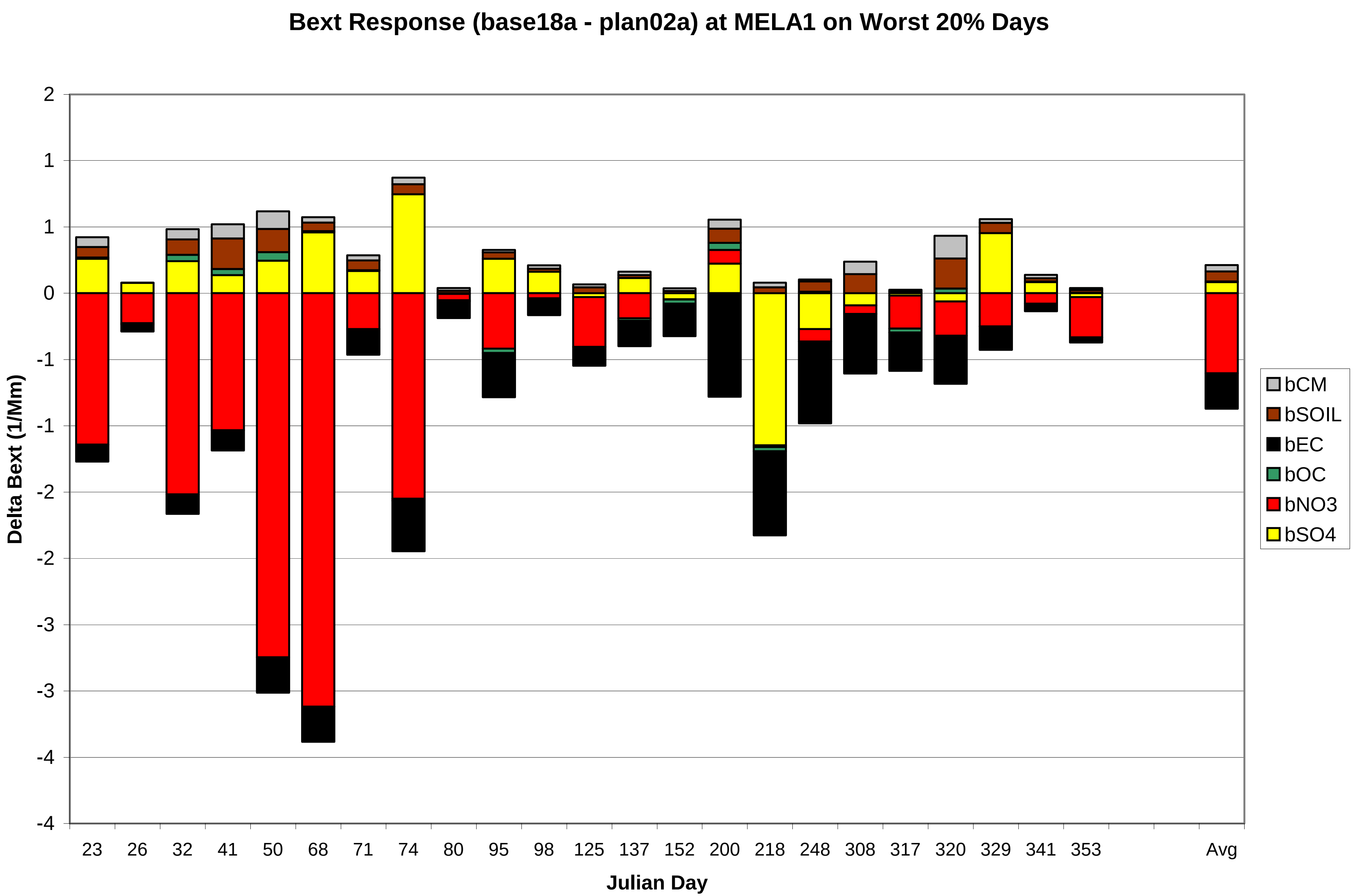


Medicine Lakes, MT
2002 IMPROVE Data
Extinction (Mm-1)
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



2002 Model Results
Extinction (Mm-1)
100
90
80
70
60
50
40
30
20
10
0
Coarse Material
Soil
Elemental Carbon
Organic Material
Ammonium Nitrate
Ammonium Sulfate
Rayleigh
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

2018 Model Changes: Medicine Lakes



Glide Path: Medicine Lakes, MT